# Final Report - Addendum

## Determining the Effects of Livestock Grazing on Yosemite Toads (*Anaxyrus* [*Bufo] canorus*) and Their Habitat: An Adaptive Management Study

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## 1. Executive Summary

This report provides an addendum to Tate et al. 2010, primarily focusing on Phase II study elements from a study of livestock grazing effects on Yosemite toads (*Anaxyrus [Bufo] canorus*). Tate et al. (2010) analyzed data collected from 2006 through 2009 and focused on two response variables from the experimental grazing manipulation experiment: density of young of the year toads and breeding pool occupancy. We build on that work and add data collected in 2010 for the following analyses:
(1) generalized linear mixed model analyses of breeding pool occupancy and densities of tadpoles and young of year relative to the livestock grazing treatments with graphical presentations of toad egg mass density (an index of adult female population size) over time;
(2) graphical presentations and correlations of Yosemite toad density, annual livestock use and meadow wetness (water table), for the subset of grazed meadows;
(3) graphical comparisons of Yosemite toad populations on National Forest lands to populations in long-term ungrazed meadows in Yosemite National Park;
(4) descriptive summary of the occurrence of amphibian chytrid fungus *(Batrachochytrium dendrobatidis; Bd*) in Yosemite toads at the study meadows.
We include relevant excerpted information from the 2006-2009 analysis report along with the pertinent additional analysis results here; refer to Tate et al. 2010 for background on the study and on Yosemite toads. We also provide a summary of the Phase I work done by PSW (C. T. Liang) under a separate funding source (USDI Fish and Wildlife Service; Liang 2010, Liang et al. 2010).

Over the period of the study (2006-2010), we did not detect differences in tadpole and young of the year Yosemite toad density and breeding pool occupancy among the three livestock grazing/fencing treatments. However, variation in densities was high and is apparently strongly influenced by water year type and meadow wetness. Egg mass density (an index of adult female population size) on Sierra National Forest meadows varied over time and from meadow to meadow. Some meadows had relatively high, though variable densities and other had low and variable densities. On grazed meadows, livestock use was higher on dryer meadows than wet meadows and Yosemite toad densities were negatively correlated with both livestock use and depth to water table (dryer meadows). Breeding pool occupancy and tadpole and young of

the year densities were similar on National Forest and Yosemite National Park meadows. Substantial meadow to meadow and year to year variation was apparent, though some meadows had consistently high pool occupancy rates and densities of both life stages. Similar to the egg density results from the Sierra National Forest these results indicate that individual meadows likely play different roles in overall Yosemite toad population dynamics. Amphibian chytrid fungus (*Bd*) was detected at all but one of the study meadows, though prevalence rates were relatively low in comparison to a related toad species.

**Yosemite Toad (*Anaxyrus* [*Bufo*] *canorus*); photo by: Rob Grasso.**

## 2. Meadow Grazing Manipulation Experiment (Phase II, PSW and UC)

### 2.1. Design, Treatments, and Hypothesis

The experimental design for this study was a randomized complete block (RCBD) with five allotments (blocks) and three meadow grazing management treatments randomized within each allotment. More details on this study design are outlined in the Study Plan (provided as an Appendix in Tate et al. 2010). The treatments were:

(1) Grazing in accordance with Riparian S&Gs 120, 121 across the entire meadow (**GRZ** treatment);

(2) Exclusion of livestock from breeding (i.e., wet) areas within a meadow (S&G 53; **F**ence **B**reeding **A**rea - **FBA** treatment);

(3) No grazing within the meadow (**F**ence **W**hole **M**eadow - **FWM** treatment).

Two allotments on the Stanislaus National Forest and three allotments on the Sierra National Forest were included in this study. Originally, seventeen meadows across these allotments were selected; however, two were excluded from analysis due to atypical grazing management history (i.e., they were livestock gathering locations). One additional meadow was excluded from analysis due to incorrect treatment implementation during several years. The dataset included in the analysis was thus an unbalanced RCDB with all treatments present in 4 allotments, but only 2 treatments present in one allotment (Herring Creek Allotment, Stanislaus NF lacked the no grazing within meadow treatment [FWM]) (Table 1). In addition, two meadows in Yosemite National Park were selected to represent long-term (>15 years) ungrazed areas ("reference" [REF]) (Table 1). However, because there were only two meadows and surveys didn't start until 2007, they were not analyzed as part of the RCDB design (Table 1)

**Table 1. Background information for the final set of study meadows. Treatments are abbreviated as: grazed = GRZ, fence the breeding areas = FBA, fence the whole meadow = FWM, and long-term ungrazed/reference = REF.**

| Meadow | Code | Location | Grazing Allotment | Elevation (m) | Treatment | Survey Area (Ha) |
|---|---|---|---|---|---|---|
| Hash | HM | Sierra NF | Patterson Mountain | 2122 | GRZ | 2.3 |
| Continental | CT | Sierra NF | Patterson Mountain | 2155 | FBA | 4.2 |
| Swainson's | ST | Sierra NF | Patterson Mountain | 2258 | FWM | 0.9 |
| Cabin | CM | Sierra NF | Dinkey | 2134 | GRZ | 2.6 |
| Exchequer | EX | Sierra NF | Dinkey | 2226 | FBA | 6.4 |
| Bear Paw | BP | Sierra NF | Dinkey | 2271 | FWM | 1.5 |
| Marigold | MA | Sierra NF | Blasingame | 2543 | GRZ | 8.5 |
| Back Badger | BB | Sierra NF | Blasingame | 2519 | FBA | 1.2 |
| Mono | MM | Sierra NF | Blasingame | 2659 | FWM | 2.9 |
| Castle | CS | Stanislaus NF | Herring Creek | 2679 | GRZ | 5.9 |
| Groundhog | GH | Stanislaus NF | Herring Creek | 2589 | FBA | 3.4 |
| Bear Tree | BT | Stanislaus NF | Highland Lakes | 2542 | GRZ | 2.3 |
| Rock Top | RT | Stanislaus NF | Highland Lakes | 2613 | FBA | 0.9 |
| Snag | SN | Stanislaus NF | Highland Lakes | 2592 | FWM | 0.8 |
| Turner | TM | Yosemite NP | *National Park* | 2286 | REF | 6.5 |
| Topper | TP | Yosemite NP | *National Park* | 2438 | REF | 2.7 |

The refined hypothesis tested by the analysis reported below is that over the course of treatment implementation (2006 through 2010), Yosemite toad numbers will increase in fenced meadow treatments (FBA and FWM) relative to grazed meadows (GRZ). The grazing treatment (GRZ) serves as the control treatment (representative of ambient pre-study conditions) in this experiment, to which the meadow fencing treatments (FBA and FWM) are compared over the course of the experiment (years).

Figure 1 depicts the hypothesis, illustrating the expected **relative** trends in toad population relative to the different grazing management treatments over time (2006 [year 1] through 2010 [year 5]). Over the course of treatment implementation we expected a reduction in Yosemite toad numbers in grazed (GRZ) meadows relative to fenced meadows. In meadows with only breeding areas fenced (FBA), we expect to see some benefit to toad populations, while in completely fenced meadows (FWM) we expect to see maximum benefit to toad populations.

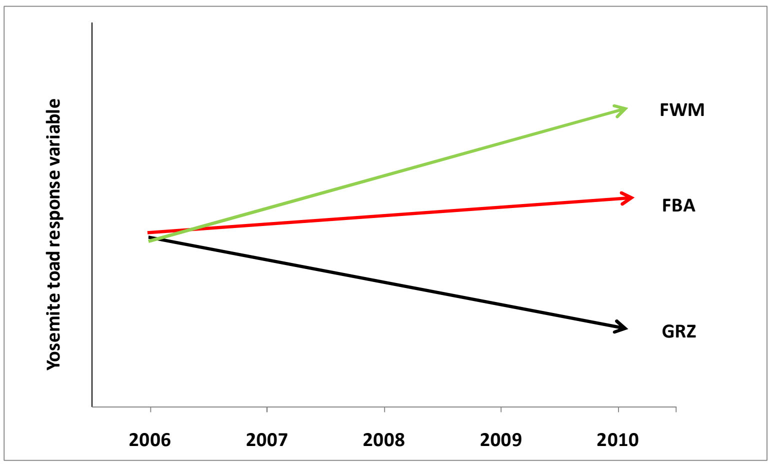



**Figure 1. Hypothesized responses of Yosemite toad density or habitat conditions to GRZ, FBA, and FWM treatments.**

### 2.2. Field Data Collection and Treatment Implementation

Data were collected on Yosemite toad population and meadow conditions from 2005 through 2010. The first year (2005) was considered a “start-up” year in which field methods were tested and equipment (e.g., piezometers to measure depth to water table) was installed. With the implementation of fencing treatments in early 2006, we began collecting data on all lifestages of Yosemite toads. This work continued through 2010 at varying levels of effort depending on access/snow conditions and other logistics (Table 2). In addition measurements of livestock utilization (measured using the paired plot, comparative yield method) and water table (using piezometers) along with other microhabtat data were collected at each meadow. For details on all field methods, see the Study Plan, especially “Data Collection Methods”, provided as an Appendix in Tate et al. 2010, and McIlroy (2008).

**Table 2. Sampling periods and Yosemite toad population data collected on the Sierra National Forest (SNF), Stanislaus National Forest (STNF), and Yosemite National Park (YNP), from 2005-2010.**

| Sampling Period | Locations and Years Surveyed | Life Stage Focus | Methods |
|---|---|---|---|
| Late spring: May /June | • SNF – all meadows 2006-2010<br>• STNF – Highland Lakes only 2006-2009<br>• YNP - 2007-2009 | Adults, Eggs | • Multiple cap-recap visits and measurements of adults<br>• Egg mass counts<br>• Amphibian chytrid fungus swabbing<br>• Individual-focused habitat data (egg masses & adults) |
| Early-mid summer: July / August | • SNF, STNF – all meadows 2005-2010;<br>• YNP 2007-2010 | Tadpoles | • Stratified hoop counts in occupied breeding pools<br>• Documentation of occupied and unoccupied pools from previous years<br>• Tadpole hoop-focused habitat<br>• Breeding pool aquatic habitat data in occupied and unoccupied pools. |
| Late summer: August / September | • SNF, STNF – all meadows 2005-2010;<br>• YNP 2007-2010 | Young of the year (YOY = newly meta-morphosed toadlets) | • Multiple cap-recap visits and measurements of YOY<br>• Breeding pool aquatic habitat and vegetation data |

From 2006 through 2009, average annual utilization across all grazed meadows (GRZ) ranged from 10-48%, while individual meadow use ranged from 0-76%. Allowable use as outlined in the Sierra Nevada Forest Plan Amendment (2004) is 40%. There was consistently high average annual utilization (36-52%) outside fences in FBA treatment meadows. This treatment reduced the area of meadow available for grazing, thus concentrating cattle, resulting in high annual utilization in the remaining areas of FBA treatment meadows (Tate et al. 2010). 2010 use data are not yet available.

### 2.3. Objectives, Analyses, and Results

The objectives of the addendum analysis were to:
(1) assess responses of breeding pool occupancy rates, tadpoles, and young of year to livestock grazing treatments, during 2006 through 2010, under the above hypothesis, and describe egg mass counts over time (an index of adult female population size);
(2) for the subset of grazed meadows (GRZ treatment only), relate toad density to annual livestock use and meadow wetness (water table);
(3) compare Yosemite toad populations on National Forest lands to Yosemite toad populations in long-term ungrazed meadows (>15 years) in Yosemite National Park, from 2007 through 2010;
(4) summarize the occurrence of amphibian chytrid fungus (*Batrachochytrium dendrobatidis; Bd*) in Yosemite toads at the study meadows.

**2.3.1. Objective 1: Meadow scale Yosemite toad population response to grazing management treatments and egg mass densities over time.**

**2.3.1.1. Analysis**

We used generalized linear mixed model regression analysis (implemented using the GLIMMIX procedure in SAS; SAS Institute Inc., 2008), to test for meadow grazing management treatment effects on: (1) annual Yosemite toad tadpole density, (2) annual young of the year (YOY) density, and (3) annual proportion of occupied breeding pools per meadow. Tadpole and YOY density and number of occupied breeding pool data were analyzed as count response variables using the log link function (Poisson family) with robust standard errors for overdispersion. Number of occupied breeding pools was analyzed as a binomial (number of occupied pools / total number of surveyed pools) with a logit link function. This approach is different from the analysis conducted by Tate et al. (2010) in which the total number of occupied pools was used as the response variable and meadow survey area was used as an exposure/offset variable. In this revised analysis, pool occupancy essentially becomes a proportion. We felt this approach carried more ecological meaning since it represents both the count of occupied pools and the proportion of aquatic habitat that is being used.

The following was the general statistical model for all analyses:

***Yosemite toad response variable ~ year + trt + meadow wetness + year × trt***

In accordance with the experimental design, the specific test of the hypothesis described above is based upon: (1) the significance of the year by treatment interaction (year × trt); and (2) the relative pattern of response among treatment meadows over time (Figure 1). The remaining fixed effect variables are covariates to account for inherent differences in toad densities or number of occupied pools between treatment groups at the outset of the study (trt), year to year variation (year), and meadow wetness (mean depth to water table; averaged for each meadow across all years [2006-2010]). The area of each meadow surveyed for Yosemite toads (survey area in hectares) was used as an offset variable to account for unequal meadow area, so this is essentially an analysis of densities. To account for repeated measures on each meadow and blocking by allotment, meadows within allotments, meadow ID, and allotment ID were specified as random effects. When significant fixed effects were found in models, we conducted pairwise comparisons (e.g., trt 1 vs. trt2 in year x) to clarify the source of the differences. We included a Tukey adjustment for these multiple t-tests.

We also evaluated densities of Yosemite toad egg masses over time, which can be used as an index of adult female toad populations. Only meadows on the Sierra National Forest were included because those meadows were consistently visited during the breeding season for all years of the study. Yosemite toads breed as soon as there are snow-free areas in meadows, and at any given meadow they typically breed over a relatively short time span (2-3 weeks). Thus, the logistics of visiting even the nine Sierra National Forest meadows during this time frame, resulted in us missing breeding at a few meadows during the course of the study. However, because we quantify egg mass counts first at the pool scale, even if some egg masses were

missed, it is possible to derive a conservative estimate of egg masses from tadpole presence. For any given pool, if only tadpoles were found, we designated that pool as having one egg mass. Because of these caveats, we did not analyze grazing treatment effects relative to egg masses in the same statistical framework that was used for the other lifestages. These data are presented graphically for this report. In the future, we may conduct statistical analyses, in combination with evaluating capture-recapture data on adults (see Section 5, Ongoing Work).

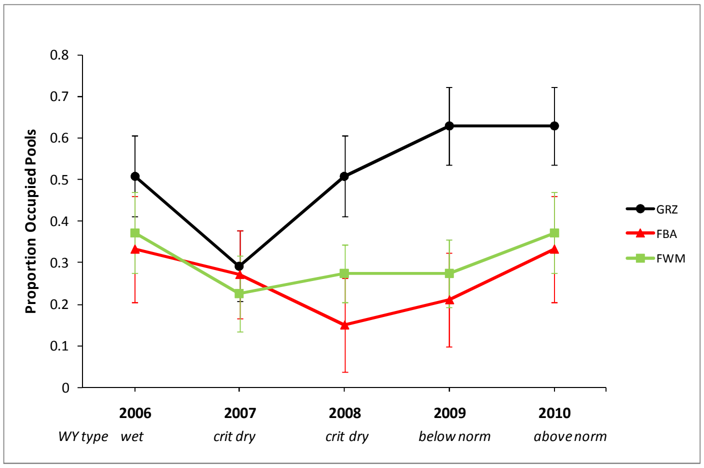
**2.3.1.2. Results – Generalized Linear Mixed Models**

Tadpole and young of the year densities, and to a lesser degree, breeding pool occupancy rates were highly variable among grazing treatments and years, but there were some significant differences for the primary fixed effects.  Different combinations of the predictor variables (year, treatment, and water table) were significant for the different Yosemite toad life stages (Table 3). However, the fixed effect that directly addressed our hypothesis and would have indicated differences among the treatments over time (year x trt) was not significant for any lifestage. Figure 2 depicts patterns of Yosemite toad occupancy and density by treatment, over time. The mean values in these figures are least square means which have been adjusted for meadow wetness and meadow survey area. The meadow wetness variable was included as covariate in all models to account for the fact that the local hydrology of the study meadows was inherently different. Even though the treatments were randomly assigned, each treatment set did not span the range of meadow wetness of the full set of study meadows; the FWM meadows were generally wetter than the meadows in the other two treatments (Figure 3). Water table was a significant fixed effect in both tadpole and YOY models. Graphs of unadjusted means are provided in Appendix A (for comparison to Tate et al. 2010).

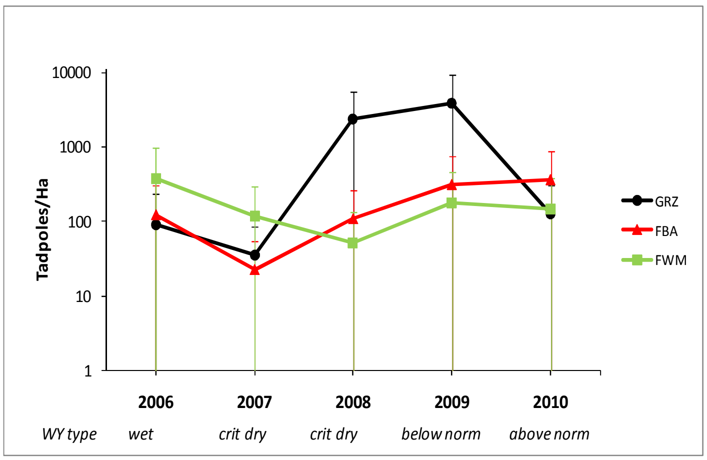
For pool occupancy, the overall fixed effect differences among treatments resulted from several pairwise differences within years (Figure 2a). Specifically, there were higher proportions of occupied pools for the grazed treatment than for the fence the breeding areas treatment in 2008 and 2009; all other pairwise tests were not significant. The water table covariate was the only significant predictor (fixed effect) of tadpole density and the relationship was negative – i.e., there were lower densities of tadpoles at meadows with higher depths to water table (dryer meadows) (Figure 4a). Both year and water table were significant predictors of YOY densities. Several pairwise differences contributed to the year effect (Figure 2c). Within the grazed treatment, there were significantly higher densities of YOY in 2008 than in 2007 and within the fence the breeding area treatment, Yosemite toad densities were significantly higher in both 2009 and 2010 than in 2007. All other pairwise tests were not significant. Water year 2007 was the driest of the study period and we suspect these differences in YOY density may be due in part to the more extended snowmelt period of 2009 and 2010 with meadows holding moisture later in the summer than in 2007. However, due to the relatively short period of the study, we cannot rule out longer term cycles that could be occurring in these populations. Similar to tadpoles, young of the year exhibit a negative relationship with dryer meadows that have deeper water tables (Figure 4b).

**Table 3 – Summary of generalized linear mixed modeling of fixed effects for each Yosemite toad lifestage. All analyses were done at the meadow scale.**

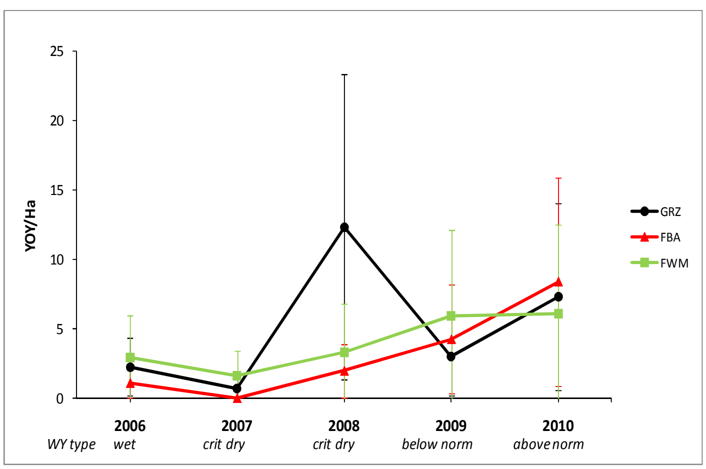
| **Yosemite Toad Lifestage (metric)** | **Description of Variable** | **Modeling Results *F*-value, *p*-value (significant results, *alpha* = 0.05, are in bold)** |
|---|---|---|
| Pool occupancy (proportion of pools) | Number of breeding pools in which viable eggs, tadpoles, or both were observed during any spring or summer visit / total pools surveyed each year | Year: 2.00, 0.110<br>Trt: **5.58, 0.007**<br>Year x Trt: 1.03, 0.429<br>Water Table: 0.96, 0.333 |
| Tadpoles (counts) | Quantitative estimate of total tadpoles based on stratified random hoop counts during one visit during the summer | Year: 2.62, 0.053<br>Trt: 0.43, 0.663<br>Year x Trt: 1.61, 0.161<br>Water Table: **5.81, 0.037** |
| Young of the year (counts of newly metamorphosed toadlets) | Average of counts from two visits during late summer | Year: **5.24, 0.003**<br>Trt: 0.81, 0.469<br>Year x Trt: 1.21, 0.327<br>Water Table: **7.49, 0.021** |




**a. Pool Occupancy**




**b. Tadpoles**




**c. Young of the Year**

**Figure 2. Yosemite toad mean (± 1 s.e.) response to grazing treatments over time: (a) pool occupancy rates; (b) tadpoles (log scale), and (c) young of the year. Sample sizes were five GRZ meadows, five FBA meadows, and four FWM meadows in each year. Means are least square means, adjusted by overall meadow water table mean (see Figure 3). Water year types are listed below each year (source: California Department of Water Resources, San Joaquin Valley Runoff from http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST).**

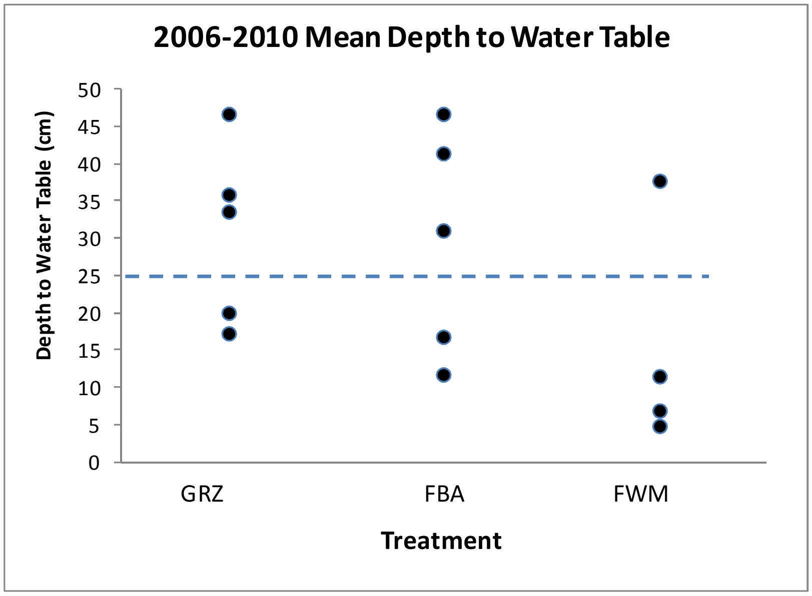
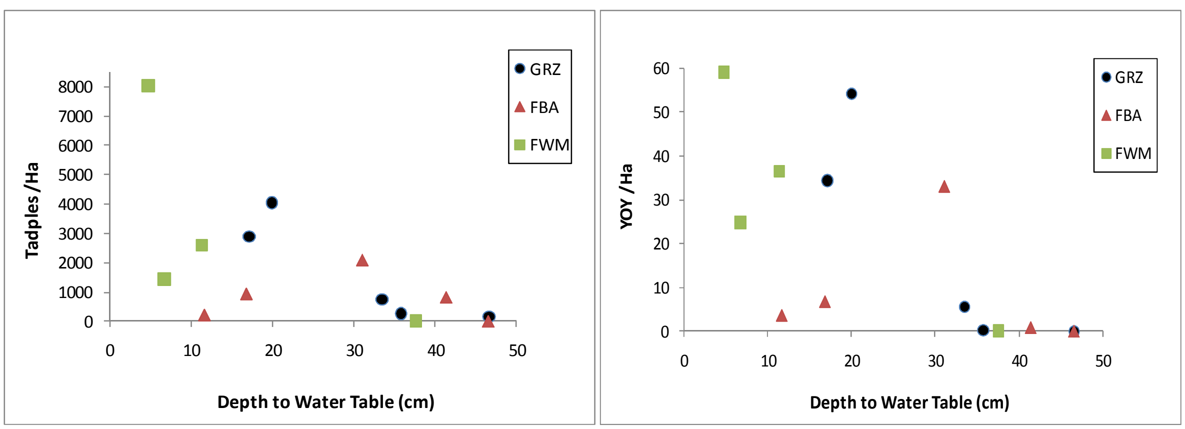



**Figure 3. Average water table depths from 2006-2010 arrayed by treatment for the 14 study meadows. Higher mean depths to water table indicate dryer meadows. The blue dashed line represents the overall mean depth to water table ( ~ 25cm); that value was used to adjust the Yosemite toad lifestage mean response in Figure 2.**




**a. Tadpoles** **b. Young of the Year**

**Figure 4. Tadpole (a) and young of the year (b) density relative to water table depths. Variables were averaged by treatment across study years (2006-2010) with five GRZ meadows, five FBA meadows, and four FWM meadows in each year.**

### 2.3.1.3. Results – Egg Mass Densities on the Sierra National Forest

Egg mass densities varied among meadows and over time: some meadows (Hash [HM], Back Badger [BB] , Swainson's [ST], and Mono [MM]) had relatively high, though variable densities over the course of the study; others had relatively low, but consistent densities (Marigold [MA], Exchequer [EX], and Bear Paw [BP]); and others had relatively low and variable densities (Cabin [CM] Continental [CT]) (Figure 5). Marigold meadow egg densities may be underestimates because this meadow was logistically difficult to get to during the breeding season and tadpoles were typically seen in some of the breeding pools on the first visit. Egg mass densities also provide an index of adult female population size. However, this is not a one-to-one relationship since some adult females may move around during amplexus and deposit small egg masses in multiple locations within a breeding pool. In general, the variation we observed indicates that certain meadows may play different roles in overall toad population dynamics; with some providing stable breeding habitat and adult populations over time and others providing habitat only periodically. This summary is presented as one piece of information that contributes to our overall understanding of Yosemite toad populations in the study meadows, and in the context of information on other lifestages and habitat relationships, it may inform land management discussions.

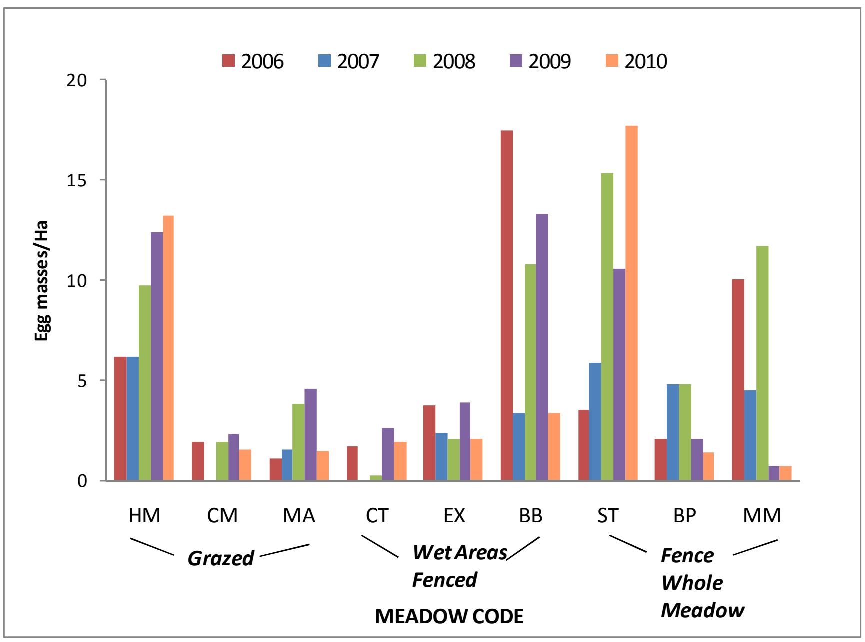



**Figure 5. Yosemite toad egg mass densities by year for Sierra National Forest meadows from 2006 through 2010. Meadows are arrayed by grazing treatment. Meadow codes are in Table 1.**

### 2.3.2. Objective 2: Relationship of toad density to annual livestock use and meadow wetness for grazed (GRZ) meadows.

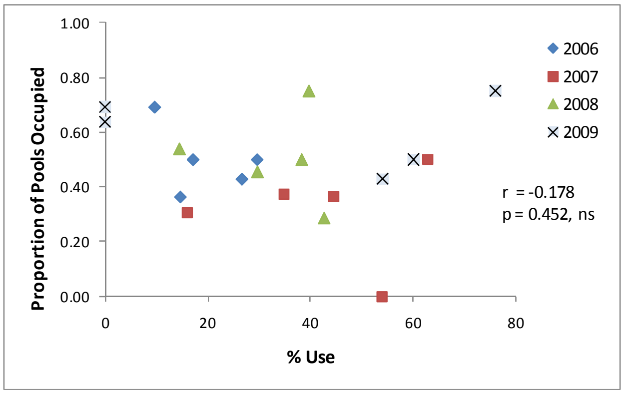
#### 2.3.2.1. Analysis

The intent of this analysis was to describe relationships among Yosemite toad densities, breeding pool occupancy, livestock use, and meadow wetness. Only the set of grazed (GRZ treatment) meadows were included because in the fenced meadows, livestock use was uncommon (e.g., temporary entry through sections of broken fence) and a broader analysis would be confounded with the fencing treatment. This analysis, which uses Yosemite toad densities as the response, compliments the presence/absence toad response analysis presented in Section 5 (Phase I) of Tate et al. 2010. It is also provided to aid in decisions about grazing management. For example, this data may inform discussions on Yosemite toad conservation relative to livestock use standards across a range of meadow hydrologic conditions.

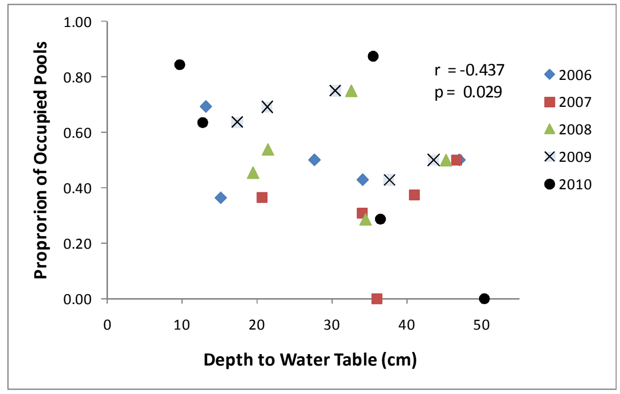
Because the set of grazed meadows was small (n=5, replicated over time from 2006-2009 for livestock use and from 2006-2010 for meadow wetness), we performed descriptive statistical analyses only. We present bivariate scatterplots and Pearson correlation coefficients for pairswise combinations of Yosemite toad breeding pool occupancy and density, livestock use, and depth to water table.

#### 2.3.2.2. Results

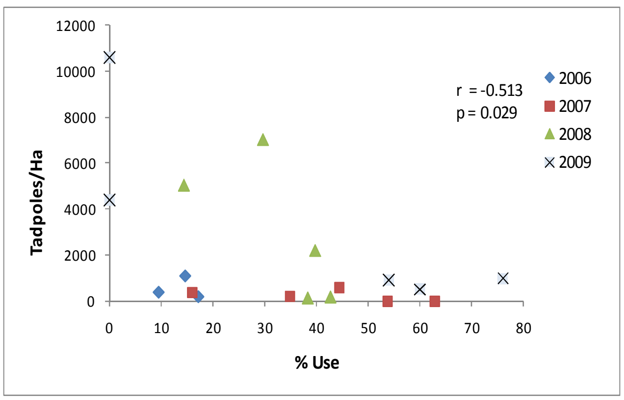
We found negative relationships between toad response variables and both livestock use and depth to water table using correlation analyses. The degree of effect was substantially greater for depth to water table than for use (as evidenced by *r* values) and many of these relationships were statistically significant (Figure 6). Tadpoles were the only lifestage with a statistically significant negative relationship to livestock use (Figure 6b). However, the highest densities of both tadpoles and young of the year were found in meadows where livestock use was ~40% or less. Proportion of occupied pools and both lifestages were significantly negatively correlated to depth to water table (meadow dryness) (Figure 6d, e, and f).



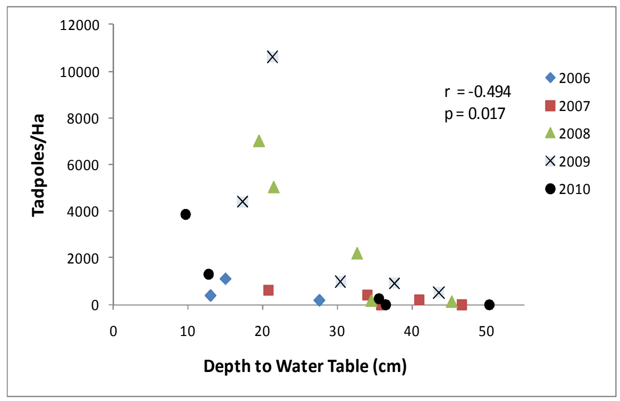

**a. Occupied Pools and Livestock Use**



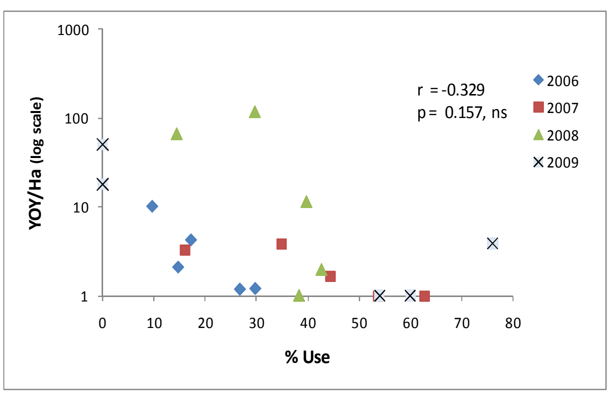

**d. Occupied Pools and Depth to Water Table**



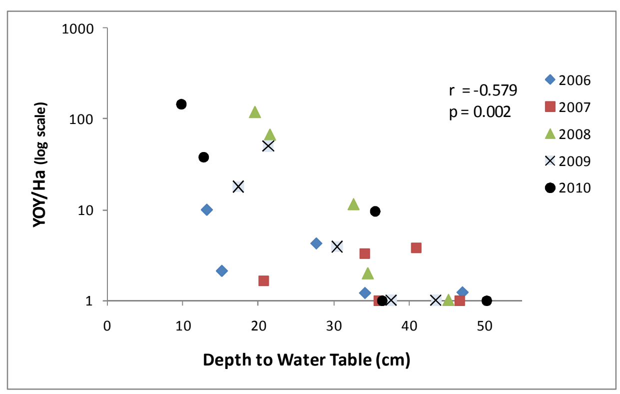

**b. Tadpoles and Livestock Use**




**e. Tadpoles and Depth to Water Table**




**c. YOY (log scale) and Livestock Use**




**f. YOY (log scale) and Depth to Water Table**

**Figure 6. Yosemite toads relative to livestock use and depth to water table. Left panel shows (a) pool occupancy, (b) tadpoles, and (c) young of the year relative to livestock use and the right panel shows (d) pool occupancy, (e) tadpoles, and (f) young of the year relative to depth to water table. Higher values for water table depth indicate dryer meadows. YOY are presented on a log scale. Different symbols indicate different years but the Pearson correlation coefficient and statistical significance (*alpha* =0.05; ns = not significant) was derived from all years combined. Use data were available from 2006 through 2009 only.**

Consistent with Phase I analysis in Tate et al. (2010), we found a significant positive relationship between livestock use and depth to water table (dryer meadows; Figure 7). This correlative analysis and the Phase I analysis (regression and structural equation modeling) from Tate et al. (2010) indicate that there may be only moderate overlap in meadow conditions that promote relatively abundant Yosemite toad populations and the meadow conditions that provide high value for livestock grazing.

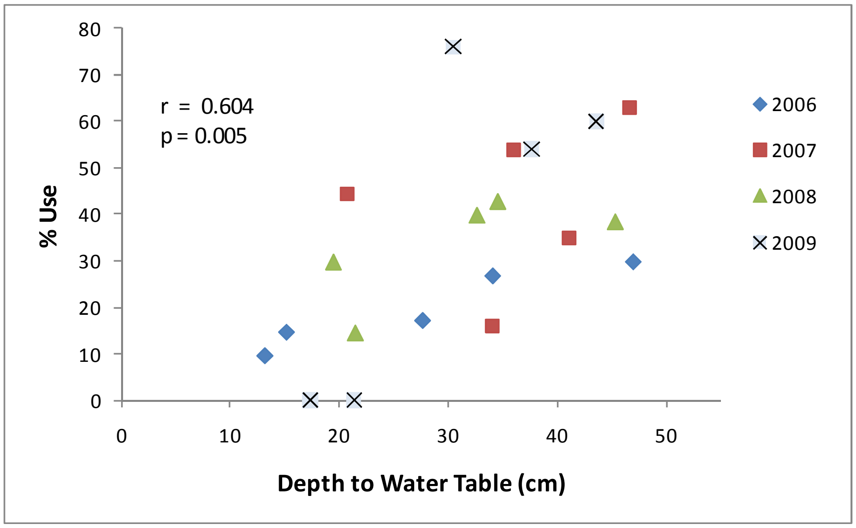



**Figure 7. Livestock use relative to depth to water table. Higher values for water table depth indicate dryer meadows. Different symbols indicate different years but the Pearson correlation coefficient and significance level was derived from all years combined. Use data were available from 2006 through 2009 only.**

### 2.3.3. Objective 3: Comparisons of Yosemite toad populations on National Forest lands to populations in long-term ungrazed meadows in Yosemite National Park.

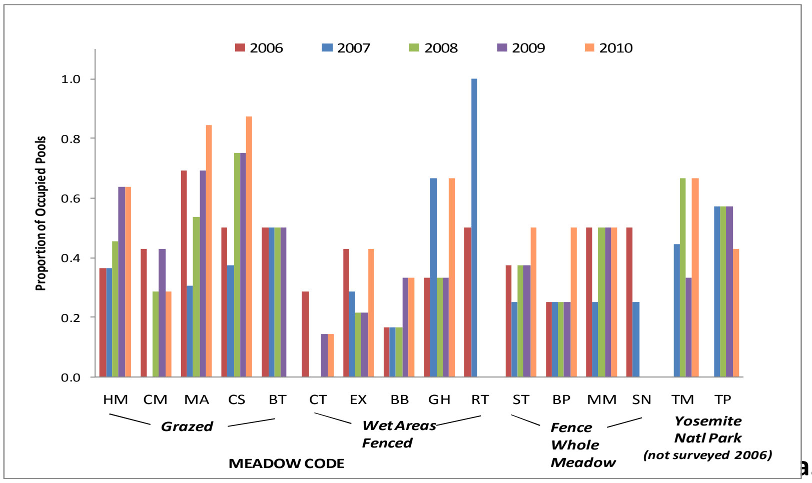
#### 2.3.3.1. Background and Analysis

The original design for this study was to include a fourth treatment – meadows representing long-term ungrazed (>15 years) conditions or “reference meadows” (see Study Plan, Appendix A in Tate et al. 2010). In 2005 and 2006, we conducted extensive reconnaissance of meadows on National Forest lands within less accessible portions of the study allotments and in adjacent closed allotments. This work did not yield a set of comparable meadows to function as the long-term ungrazed treatment, so in 2007 we added study meadows in Yosemite National Park (YNP). The Park is geographically situated between the Stanislaus and Sierra National Forests and two meadows were selected at a similar elevation and with similar vegetation composition to the National Forest study meadows.

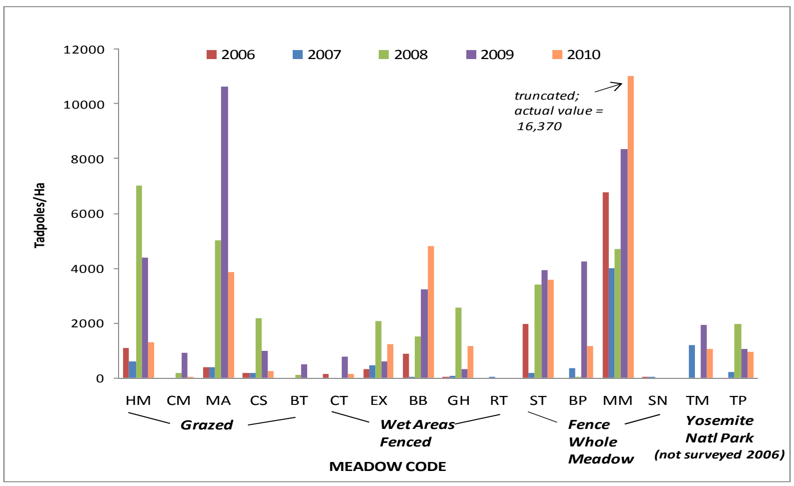
The two YNP meadows were not analyzed as part of the RCDB design (Section 2.4.1 above) because there were only two (there were five for the other treatments) and surveys at these meadows didn’t start until 2007. The survey data from these meadows provides a point of reference and context for evaluating Yosemite toad densities and breeding pool occupancy on National Forest meadows. We present graphs of Yosemite toad lifestages arrayed by grazing treatment alongside reference meadow data.

#### 2.3.3.2 Results

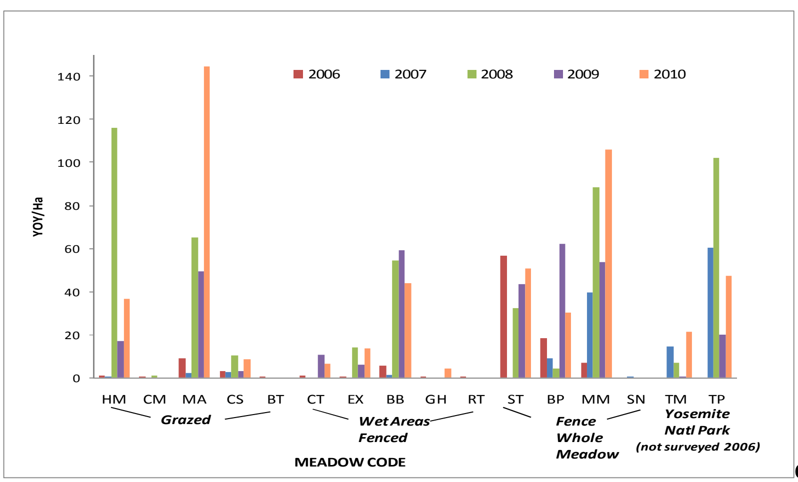
Yosemite toad populations on the National Forests appear to be similar to those in Yosemite National Park. Similar to egg mass density results (presented in Section 2.4.1.3), there is substantial meadow to meadow and year to year variation for all lifestages (Figure 8). Breeding pool occupancy rates were the most similar between National Forests and Yosemite National Park; most meadows ranged from 30-60 % of pools occupied each year, though a few had consistently higher rates across years (e.g., Marigold [MA] and Castle [CS]). Several meadows also showed no breeding in a few years (e.g., Continental [CT], Rock Top [RT] and Snag [SN]) (Figure 8a). Tadpole and young of the year densities were similarly variable on the National Forests and in Yosemite National Park. Tadpole densities were relatively lower in Yosemite National Park than on some of the National Forest meadows, but young of the year densities in the Park were similar to the National Forest meadows with consistently high densities (Figure 8b and c). The meadows that had high numbers of tadpoles also tended to have high numbers of young of the year and some meadows had consistently high values for both (e.g., Marigold [MA], Swainson’s [ST], Mono [MM]). Across all meadows and years, these patterns point to the fact that some meadows provide stable breeding and rearing habitat in most years and others only provide good quality breeding and rearing habitat periodically.




a. Pool Occupancy




b.Tadpoles




c.Young of the Year

**Figure 8. Yosemite toad occupancy and density for each of the study meadows by year for 2006-2010: (a) pool occupancy rates; (b) tadpoles, and (c) young of the year. Meadows are arrayed by grazing treatment and Yosemite National Park data are shown on the far right of each graph. Meadow codes are in Table 1.**

### 2.3.4. Objective 4: Summary of the occurrence of amphibian chytrid fungus (*Batrachochytrium dendrobatidis; Bd*.) in Yosemite toads at the study meadows.

#### 2.3.4.1. Background

Chytridiomycosis is a common amphibian disease caused by the fungus, *Batrachochytrium dendrobatidis* (*Bd*). Both lethal and sub-lethal effects have been documented on species around the world (Berger et al. 1998, Skerratt et al. 2007). Some amphibian species are highly affected by the disease (e.g., Sierra Nevada yellow-legged frog [*Rana sierrae*] in the Sierra Nevada of California, and boreal toads [*Anaxyrus* [*Bufo*] *boreas*] in the Rocky Mountains), while others are not affected (Daszak et al. 2004, Muths et al. 2003, Vredenburg et al. 2005). Because populations of the Yosemite toad may be susceptible to *Bd* (Sherman and Morton 1993), we collected samples to investigate the potential effects of the disease on Yosemite toad populations in the study meadows.

#### 2.3.4.2. Methods

Five hundred *Bd* swab samples were collected from Yosemite toads in 2006 through 2010 at study meadows on the Stanislaus National Forest, Sierra National Forest, and Yosemite National Park. Up to 25 individual swab samples were collected at each survey meadow per season. We prioritized adults (snout-vent length [SVL] greater than 40mm) for sampling, though we also collected samples from juveniles (SVL 25-40mm) and young of the year (SVL less than 25mm). The sampling protocol was adapted from C. Briggs (pers. comm.) and Boyle et al. (2004) and involved swabbing each toad multiple times with a single swab, air drying the swab in the field, and then storing it on ice or in a refrigerator in an individual tube, until it could be processed. Each swab was processed using standard laboratory genetic techniques for detecting and quantifying *Bd* status (positive/negative) and zoospore loads (Boyle et al. 2004; V. Vredenburg, pers. comm.).

#### 2.3.4.3. Results

Four hundred and twelve of the 500 samples were from unique individuals; the remaining 88 samples were second or third captures of the same individuals over the course of the study. *Bd* was detected at all but one study meadow, but only one sample was taken at that meadow. Of the 500 samples, 17.0% were positive for *Bd*. Table 4 provides a summary of the number of samples by sex and lifestage and prevalence (number positive divided by the total number) for each category. When combining data from all study meadows, *Bd* occurs at a higher prevalence in adult males (14.6% positive) than in adult females (10.9%) and has an even higher prevalence in juveniles (31.8%). *Bd* prevalence in young of the year was lower (20.3%) than in juveniles, although still higher than adults. However, these apparent differences still need to be assessed at a meadow/population scale, and tested statistically. The prevalence rates we observed are lower than those found for a related species - boreal toads in the Rocky Mountains. There, over a six year study, *Bd* prevalence in adult male boreal toads averaged 53% and 62% at two *Bd* positive sites; toads at one other site in the study were consistently negative for *Bd* (Pilliod et al. 2010).

**Table 4. Summary of results from sampling for amphibian chytrid fungus (*Bd*) in Yosemite toad populations occurring in Phase II study meadows from 2006-2010.**

| Year | Number of Locations[1] | Young of the Year | Juveniles & Subadults | Adult Females | Adult Males | Totals By Year |
|---|---|---|---|---|---|---|
| **2006** | **SNF, STNF: 15 meadows** | 0 | 0 | 15 | 63 | 78 |
| **2007** | **SNF, STNF, YNP: 16 meadows** | 1 | 2 | 13 | 57 | 73 |
| **2008** | **SNF, STNF, YNP: 18 meadows** | 0 | 23 | 32 | 70 | 125 |
| **2009** | **SNF, STNF, YNP: 15 meadows** | 28 | 23 | 12 | 37 | 100 |
| **2010** | **SNF, STNF, YNP: 14 meadows** | 45 | 18 | 20 | 41 | 124 |
| | **Totals by Life Stage** | 74 | 66 | 92 | 268 | 500 |
| | ***Bd* positive 2006-2010** | 15 | 21 | 10 | 39 | 85 |
| | ***Bd* negative 2006-2010** | 59 | 45 | 82 | 229 | 415 |
| | **% Bd pos** | 20.3% | 31.8% | 10.9% | 14.6% | 17.0% |

[1] SNF=Sierra National Forest, STNF=Stanislaus National Forest, YNP=Yosemite National Park

## 3. Yosemite Toad Species Distribution Model Summary (Phase I, PSW)

Species distribution models were developed for Yosemite toads on the Sierra National Forest using survey data collected by the Forest in conjunction with a set of environmental data (e.g., precipitation, land management) collected during the surveys or developed from Geographical Information Systems (GIS) data. Analysis of this data was done at the site/meadow scale and results were presented previously in Liang (2010) and Liang et al. (2010). Due to inconsistencies in site/meadow-scale collection of livestock and packstock data and the lack of quantitative data on livestock use and/or stocking rates at the site/meadow scale, this analysis did not include an assessment of livestock use relative to Yosemite toad distribution. A secondary effort to compile and analyze information from Sierra National Forest grazing allotment files is in process (see Section 5, Ongoing Work, below).

Visual encounter surveys were conducted from 2002 through 2004 to determine the presence of Yosemite toads at over 2,200 sites/meadows covering its known geographic range on the Sierra National Forest. Each site was visited at least once during the survey period and the visit was timed to coincide with tadpole presence in the late spring/early summer. Presence was defined by the sighting of any lifestage (egg, tadpole, metamorph/YOY, juvenile, or adult). Sites were considered to be unoccupied (not present) for a particular survey if no lifestages of the Yosemite toad were seen. Environmental variables such as air and water temperatures were also recorded during the site visit and were used in the species distribution modeling.

Three different species distribution models were developed: one that included all available biological, physical and management based variables (full model); a second model that focused on biological and physical variables only (biophysical model); and a third model that focused on variables related to management only (management model). The status of Yosemite toads (present/not present) was the response variable and analyses were done at the meadow/site scale. Fifty-four predictor variables, representing both field survey data and environmental data available from GIS, were initially assessed for the full model. Each variable was tested statistically for inclusion (using both forward and backward step-wise selection in a generalized linear model) and the set of variables which collectively performed the best (had the lowest Akaike's Information Criterion value) were included in each of the three models.

Sixteen predictor variables were included in the best full model, including both biophysical and management variables. The best biophysical model included eleven predictor variables and the best management model included six predictor variables. Some of the variables were positively correlated with Yosemite toad presence (i.e., as the value of the variable increased, toads were more likely, or had higher odds, of presence at a site), and other variables were negatively correlated with presence (i.e., as the value of the variable increased, toads were less likely, or had lower odds, of presence at a site). Table 5 lists the top five variables (based on effect size using odds ratios) that were included in each of the three final models, and indicates which variables were positively or negatively related to toad presence. A complete list of the variables evaluated is provided in Liang (2010).

Overall, the Yosemite toad appears to have a complex relationship with the environment and is not dependent on any single environmental factor. Although the biophysical or management related subset models alone can predict Yosemite toad occurrences, the full model had the best predictive ability. Thus, both types of factors influence Yosemite toad occurrence and need to be considered in order to understand its distribution and effectively manage both populations and habitat.

**Table 5. Yosemite toad distribution models and the top variables associated with each. For variables that are positively related to presence, higher values of the variables results in higher odds of Yosemite Toad occurrence. For variables that are negatively related to presence, higher values of the variables results in lower odds of Yosemite toad occurrence.**

| Model | Description | Positively Related To Presence | Negatively Related To Presence |
|---|---|---|---|
| **Full** | Both biophysical and management related variables | • Annual snow cover area (75-100% covered in snow)<br>• Land cover changes from 1985-1991<br>• Elevation<br>• Land cover changes from 1990-1995<br>• Water temperature | • Temperature seasonality<br>• Y-coordinate (more northerly sites had a lower odds of Yosemite toad presence)<br>• Precipitation of driest quarter<br>• Air temperature<br>• Slope |
| **Biophysical** | Biological and physical variables relating to environmental variation only | • Water temperature<br>• Spatial autocorrelate (sites with Yosemite toads in nearby meadows had a higher odds of Yosemite toad presence)<br>• Precipitation of warmest quarter<br>• Elevation<br>• Aspect | • Air temperature<br>• Precipitation of driest quarter<br>• Slope<br>• Y-coordinate (more northerly sites had a lower odds of Yosemite toad presence)<br>• Temperature seasonality |
| **Management** | Management related variables only | • Land cover changes from 1985-1991<br>• X-coordinate (more easterly sites had a higher odds of Yosemite toad presence)<br>• Land cover changes from 1990-1995<br>• Spatial autocorrelate (sites with Yosemite toads in nearby meadows had a higher odds of Yosemite toad presence) | • Fire regime alteration from historical range<br>• Distance to timber activity (sites further from timber activity had a lower odds of Yosemite toad presence). |

## 4. Conclusions

- Over the period of the study (2006-2010), we did not detect differences in Yosemite toad density and breeding pool occupancy among the three livestock grazing/fencing treatments. However, variation in the densities was high and is apparently strongly influenced by water year type and meadow wetness (water table).

- The year to year variation we observed may be a function of longer-term population cycles. This five-year study covered a relatively short time period, considering that Yosemite toads are fairly long-lived (10-15 years) and females do not reproduce for the first time until they are 4-5 years old. Thus, if there is an effect of the livestock grazing treatments on the population as a whole, it might not be evident for at least a generation.

- As implemented, the fence the breeding areas (FBA) treatment was not a “good” test of S&G 53 because fences covered very large areas and grazing use was over standard in the areas outside of the fences. Nevertheless, this treatment as implemented does not appear to provide a clear benefit to Yosemite toads.

- Egg mass density (index of adult female population size) on Sierra National Forest meadows varied over time and from meadow to meadow. Some meadows had relatively high densities and other had low and variable densities.

- On grazed meadows (GRZ), livestock use was higher on dryer meadows than wet meadows and Yosemite toad densities were negatively correlated with both livestock use and depth to water table (dryer meadows). These relationships can inform management of meadows and livestock, and conservation of Yosemite toads.

- Breeding pool occupancy and tadpole and young of the year densities were similar in National Forest and Yosemite National Park meadows. Substantial meadow to meadow and year to year variation was apparent, though some meadows had consistently high occupancy rates and densities of both life stages.

- The egg density results from the Sierra National Forest and the results of comparisons of National Forest and Park populations indicate that individual meadows likely play different roles in overall Yosemite toad population dynamics. Identifying key meadows and understanding these spatial dynamics will be important elements in the development of conservation options for Yosemite toads.

- Amphibian chytrid fungus (*Bd*) was detected at all but one of the study meadows, though prevalence rates were relatively low in comparison to a related toad species.

- Yosemite toad distribution across the Sierra National Forest is driven by a combination of environmental (biophysical) and land management factors and these complex relationships should be considered in meadow management and in the development of Yosemite toad conservation options.

## 5. Ongoing Work

The following work will be conducted over the next 6 months to 1 year.

Phase II

- Analyze detailed microhabitat data, taken at all Yosemite toad egg mass and tadpole locations and at unoccupied pools, to determine key habitat variables for successful recruitment. This analysis builds on water quality and cover analyses provided in Tate et al. 2010 (Sections 4.5 and 4.6) but includes all occupied pools and a comparable set of unoccupied pools on both National Forests and in Yosemite National Park.
- Analyze adult and juvenile toad population characteristics and ecology (e.g., egg mass characteristics, age and sex ratios, growth rates, size at metamorphosis).
- Analyze occurrence of amphibian chytrid fungus (*Bd*) in the study meadows relative to water year types, meadow wetness, and livestock grazing treatment.

Phase I

- Allotment scale information on livestock stocking rates (e.g., cow/calf pairs per month) has been compiled and a distribution model for Yosemite toads at the allotment scale is currently being developed.

## 6. Acknowledgments

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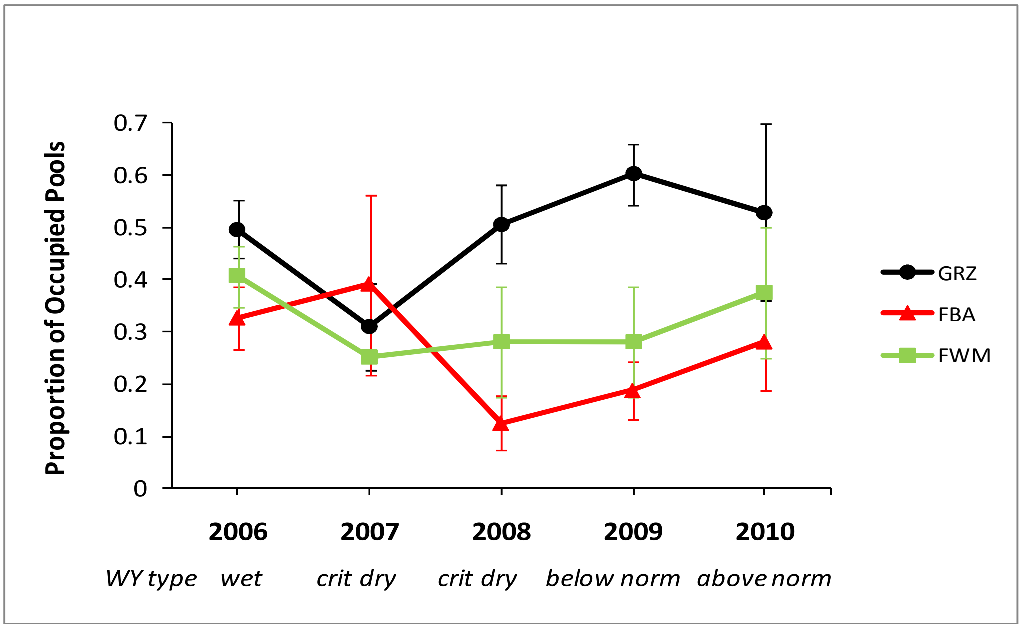
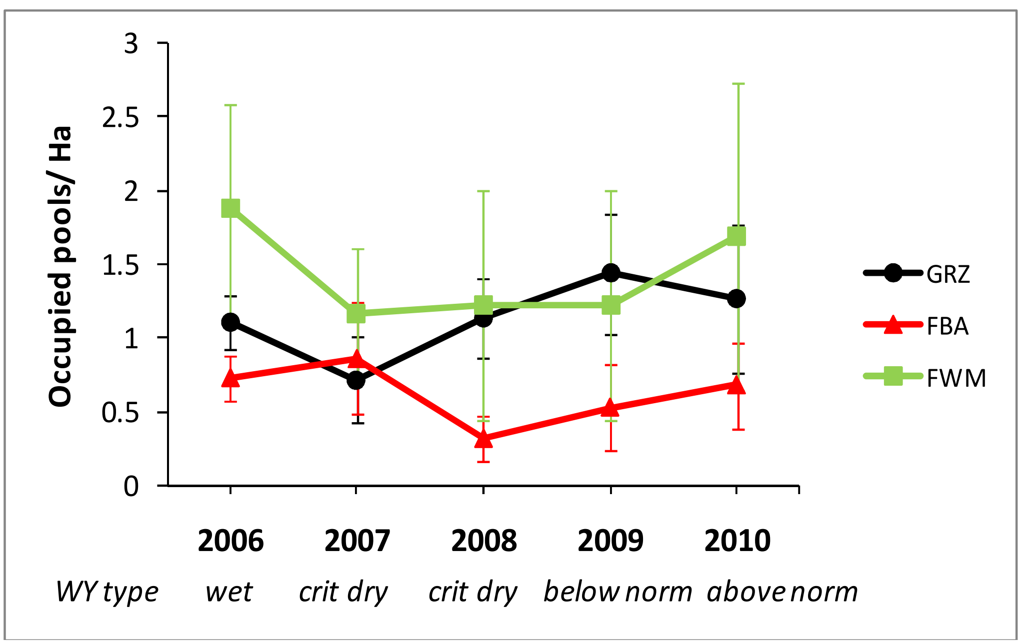
**Appendix A. Unadjusted (for meadow wetness/water table) Yosemite toad mean (± 1 s.e.) response to grazing treatments over time: (a1) pool occupancy rates and (a2) occupied pools per hectare (for comparison to Tate et al. 2010); (b) tadpoles (log scale), and (c) young of the year. Water year types are listed below each year (source: California Department of Water Resources, San Joaquin Valley Runoff from http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST).**

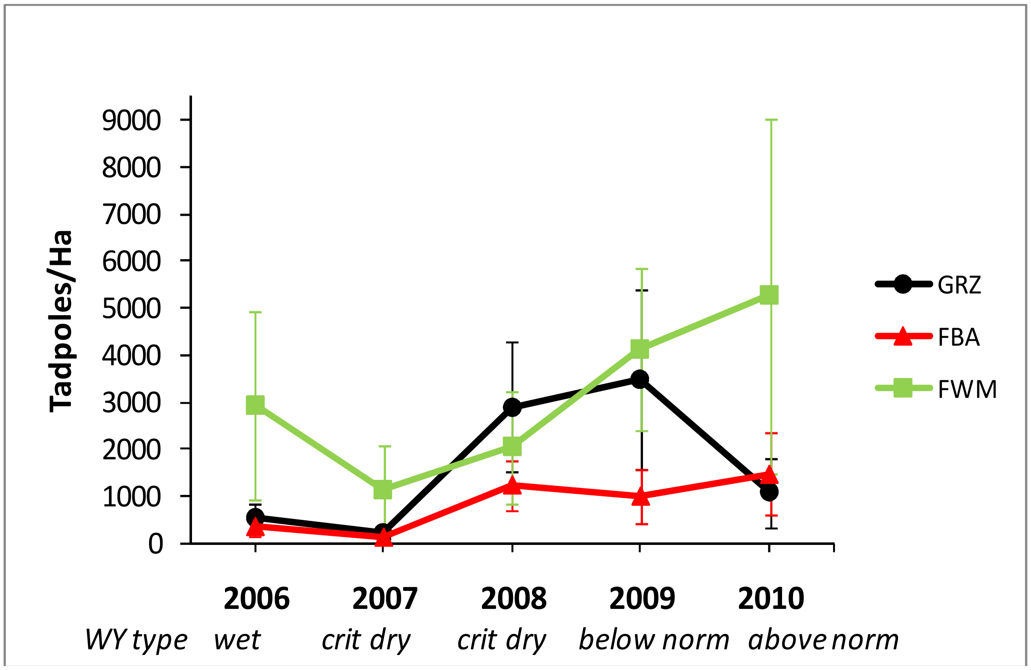



**a1. Pool Occupancy**

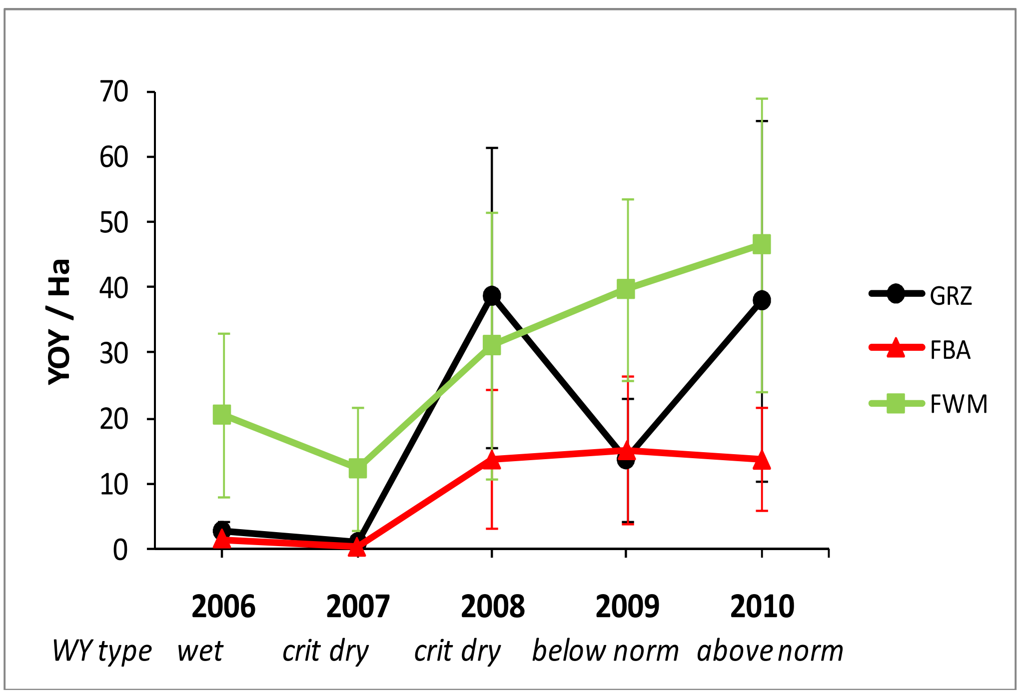



**a2. Occupied Pools / Ha**

**Appendix A., *continued***




**b. Tadpoles**




**c. Young of the Year**